International Journal of Engineering Research (ISSN : 2319-6890)
Volume No.2, Issue No. 6, pp : 399-403 01 Oct. 2013

A Concentrated Solar Power Unit Collector's Efficiency under varied wind speeds

[1]Ajay Vardhan, [1]A.C. Tiwari, [2]Arvind Kaushal, [3] Sunil Hotchandani,
[1]University Institute of Technology-RGPV, Bhopal (M.P.)-462001
[2]Samrat Ashok Institute of Technology, Vidisha (M.P.) -464001
[3]Department of Civil Engineering (Environment Engineering), Bhagwant University, Ajmer (Raj)-305009
E-mail id: a_v1986@rediffmail.com

Abstract

Concentrated Solar Power (CSP) harnesses the sun's solar energy to produce electricity. This report provides a technical analysis of the potential for CSP to provide low cost renewable electricity in Bhopal (M.P.) and outlines the impact of varied wind speeds on its collector's efficiency. Yields of CSP Plants depend strongly on site-specific meteorological conditions. Meteorological parameters that can influence the performance of CSP plant are Direct Normal Irradiance (DNI), wind, ambient air temperature and humidity. The concentrated solar thermal power system constructed for this system follows that of conventional design of a parabolic concentrator with the receiver placed along the line between the centre of the concentrator and the sun. The concentrator receives approximately 1124.82W/m^2 of solar insolation (dependent upon time of year), which is concentrated and reflected to the receiver. By concentrating the incoming radiation, the operating temperature of the system is increased significantly, and subsequently increases the efficiency of the conversion from sunlight to electricity. For the current system, with a concentration ratio of 495, the concentrator is theoretically capable of producing temperature upwards to 712 degrees centigrade. It was found that the collector (concentrator + receiver) yields an efficiency of 95.6 percent. This study investigates the potential for our intervention to accelerate the deployment of small-scale concentrated solar power (CSP) in various parts of Bhopal (M.P.)

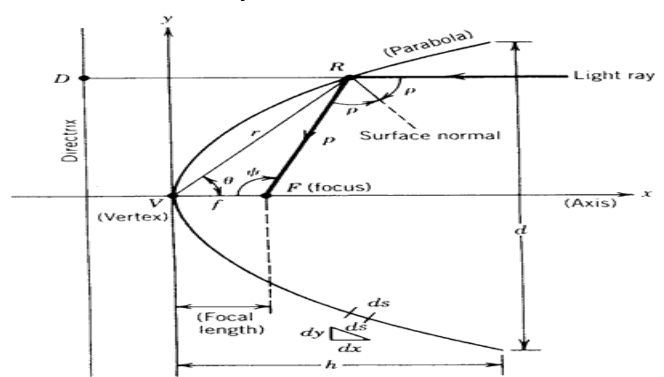
Introduction

The basic principle of solar thermal collection is that when solar radiation is incident on a surface (such as black body) a part of this radiation is absorbed and causes to increase the temperature of the surface.The typical solar flux concentration ratio typically obtained is at the level of 30–100, 100–1000, and 1000–10000 for trough tower and dish systems, respectively. The solar radiation incident on the Earth's surface is comprised of two types of radiation- beam and diffuse, ranging in the wavelengths from the ultraviolet to the infrared (300 to 200 nm), which is characterized by an average solar surface temperature of approximately 6000 degree Kelvin. The amount of this solar energy that is intercepted is 5000 times greater than the sum of all other inputs – terrestrial, nuclear, geothermal and gravitational energies and lunar gravitational energy.

When dealing with solar energy, there are two basic choices. The first is photovoltaics, which is direct energy conversion that converts solar radiation to electricity. The second is solar thermal, in which the solar radiation is used to provide heat to a thermodynamic system, thus creating mechanical energy that can be converted to electricity. In commercially available photovoltaic system, efficiencies are on the order of 10 to 15 percent, where in a solar thermal system, efficiencies as high as 30 percent are achievable. This work focuses on the electric power generation of a parabolic concentrating solar thermal system

Parabolic Geometry

A parabola is the locus of points that moves equal distance from a fixed line and a fixed point. As shown in Fig.1, the fixed line is called the directory and the fixed point is the focus F. The line perpendicular to the directory and passing through the focus F is called the axis of the parabola. The parabola intersects its axis at a point V which called the vertex, which is exactly midway between the focus and the directory.



Experimental Apparatus and Procedures

1. **Introduction**

This work was focused on the development of a system for converting incoming solar radiation to electrical energy. The system concentrated the incoming solar radiation to power a thermal cycle in which the energy was converted to mechanical power, and subsequently to electrical power. This chapter contains a description of this system and a detailed explanation of how the individual components of the system work. The design, implementation, and testing of

the system were conducted at the University Institute of Technology, RGPV, Bhopal, Madhya Pradesh.

2. Solar Collector

To obtain the high temperatures necessary, a concentrating solar collector is needed due to solar radiation being a low entropy heat source. The type chosen was that of the parabolic 'dish' type. The parabolic dish is a 3.99 meter diameter Channel Master Satellite dish, obtained from….The dish consists of six fiberglass, pie-shaped, sections which are assembled together to form the parabolic structure of the dish

3. The Receiver

The receiver of the solar concentrator system serves as the boiler in the Rankine cycle, thus it needed to be able to handle high temperatures. This first generation receiver was designed with simplicity in mind for characterization of the system. An external type receiver was decided upon for use with the concentrator. The basis behind the design of the receiver was a standard D-type boiler, with a mud (water) drum, steam drum, and down-corners. Because of the extreme temperatures expected at the focal region, in excess of 900 K, the outer housing of the receiver was constructed of stainless steel. The receiver consists of a stainless steel cylindrical water drum and two sets of stainless steel coils housed within a stainless steel welded tube. The outer shell of the boiler is 250m long and 195m in diameter, with an internal volume of 3.245 liters. The water drum is 38.1 mm (1.5 in) tall and 133.5 mm (5.25in) in diameter, with a volume of 0.0402 liters. The inner coils consists of 25.4mm (1/4 inch) stainless steel tubing, one set coiled within the other, with the outer and inner coils consisting of fourteen windings with a diameter of 133.35 mm (5.25in) and six windings with a diameter of 63.5 mm (2.5in), respectively.

The outer shell is filled with a molten salt into which the water drum and coils are submerged. The molten salt is known as Draw Salt, which consists of a 1:1 molar ratio of Potassium Nitrate (KNO_3 – 101.11 grams per mol) and Sodium Nitrate ($NaNO_3$ – 84.99 grams per mol). There is a total of 19.39 Mols of Draw Salt in the thermal bath, The Draw Salt serves as latent heat storage to allow for continuous heat transfer in the case of intermittent cloud cover and for equal thermal distribution over the water drum and the coils.

The receiver is set up to record the inlet, outlet, and thermal bath temperatures, along with the outlet steam pressure. Three stainless steel sleeved K-type thermocouples, with ceramic connectors, are used for temperature measurements. The thermocouples are located at the inlet and exit of the rreceiver to measure the incoming water and exiting steam temperature. The third thermocouple is submerged halfway into the thermal Draw Salt bath. Figure shows the location of the thermocouples on the receiver. With the receiver assembled, it was then placed at the focal region of the concentrator. The supporting structure for the receiver and the area of the receiver not subject to concentrated solar intensity ws then covered with Kaowool Superwool insulation;

4. Steam Turbine

It was decided that a single stage impulse turbine would best meet the system requirements of simplicity and use in developing areas. Design plans were purchased from Reliable Industries, Inc. for the T-500 turbine.

5. Working Fluid of Solar Thermal System

Since the design of this system was to be kept as simple as possible, water was chosen as the working fluid. If the system were set up off-grid in a field, then a well could be used to supply water for the solar thermal system. In the event that a water-well is unavailable, as was the case here, a reservoir for the water is needed. A steel constructed tank, with a capacity of 13 litres (approx. 3.43 gallons) is used. Because of the conditions for which the system was designed, such as off-grid and emergency use, the water does not need filtered. However, if the water being used is full of debris, maintenance of the system will need to be performed more frequently, thus the use of a screen over the inlet supply line of the pump is suggested, but not necessary.

6. Pump

The water is supplied to the system from the tank by use of a Fluid-O-Tech pump located on the underside of the dish. The pump has a small foot print, with the motor having dimensions of 127mm * 114 mm * 109 mm, and the controller, 93 mm * 115 mm * 83mm. The pump has variable speed and power settings, ranging from speeds of 1000 rpm to 3500 rpm, and power settings from 30 percent to 85 percent. The pump runs off of 100 volt to 110 volt AC, with a maximum power usage of 250 Watts. The power setting on the pump has no affect on the flow rate; it affects the amount of pressure that the pump can overcome at a particular speed. The speeds of the pump, however, directly correspond to the flow rate, The pump is designed for longevity by having an absence of moving parts within the motor, with only a short single shaft inside the pump. The control unit of the pump utilizes a double protection system on the circuit board, with a thermal 'cutout' to protect the pump and control unit from overheating and current protection for moments of high current peaks caused by overload or seizure of the pump. The original design of the pump was for espresso coffee machines, reverse osmosis system, cooling systems, circuit washing, and/or solar heating systems, thus it was deemed ideal for use in the solar thermal system discussed in this work.

7. Tracking

Tracking of the parabolic dish is done by a combination of satellite dish linear actuators and photo-sensing control units

that are commercially available. Due to the need for two-axis tracking, two heavy duty linear actuators were used. The actuator for altitude tracking was a SuperJack Pro Brand HARL3018, and the azimuth actuator is a SuperJack Pro Brand VBRL3024. The HARL3018 is a medium duty model, rated for a dynamic load of 600lbs, with an 18 inch stroke length equipped with limit switches. The VBRL3024, a heavy duty actuator, is rated at a dynamic load of 1500 lbs, with a 24inch stroke length and is also limit switch equipped. The heavy duty model was required for the azimuth tracking because of the East and West directional extremes required of the actuator. Each actuator requires 12 to 36 volts and up to 7.5 amps, depending on loading, for operation.

8. **Data Acquisition**

Temperature and pressure had to be constantly monitored and logged throughout the day for numerous days to be able to characterize the solar thermal system. A data acquisition system was implemented in order to avoid having to manually log these values by hand. The data acquisition system consisted of a Windows XP based personal computer, and a National Instruments Signal Conditioning Board (SCB-68). The PC used a Lab VIEW-based program named Surya after the Hindu Sun god, to acquire the temperatures of interest from the solar thermal system. The program displayed the data for quick reference of system operation throughout the day, and it logged all of the measurements with a stamp of when the data was acquired.

9. **Power Supply**

Although the system is designed to produce power, some power must be consumed in order to do so. Power was needed for the linear actuators for positioning of the dish, as well as for operation of the pump. This power was being provided by two 12-volt, valve regulated, deep cycle, AGM type Delco brand batteries,…..The batteries were wired in series to increase the voltage to 24 volts for control of the tracking.

10. **Generator/Alternator**

In order to produce electrical power from the system, a generator has to be coupled with the output shaft of the steam turbine. The generator used was a 443541-10Amp Permanent Magnet DC Generator from Wind stream Power LLC. The generator is capable of producing power at speeds ranging from 0 to 5000 rpm at voltages between 12 and 48 volts. Maximum power production for this particular generator, for 12,24 and 48 volts is 120,240 and 480 watts, respectively. F

Analysis/Results

1. **Receiver's Dimensions:**
   D_{inner}- 0.18 m
   D_{outer}- 0.195 m
   Length (L) - 0.25 m
   Height (h) - 0.23 m
2. **Collector's Dimensions:**
   Surface area of Collector- 13.7m^2
   Aperture area of concentrator- 12.56m^2
3. **Film Temperature**
   T_{outer}- 900º K
   T_{inner}- 300º K
   T_{air}- 298.1º K
4. **Property of air at 298.1º K approx**
   Thermal Conductivity, K_{air}- 0.145 W/mK
   Kinetic Viscosity, V_{air}- 47.85 * 10^{-6} m^2/s
   Prandtl no. P_n- 0.68
5. **Variation of wind velocity over the year (2012) Bhopal**

Month	Wind Speed (m/s)
January	2.1385 m/s
February	2.416 m/s
March	2.58 m/s
April	3.1 m/s
May	4.4 m/s
June	5.22 m/s
July	5.166 m/s
August	3.52 m/s
September	2.22 m/s
October	1.66 m/s
November	1.72 m/s
December	1.611 m/s

6. **Reynold Number**
   Formula: Re- V1*D_{out}/ Kinetic Viscosity (*V*)

Month	Reynold Number (Re)
January	8689.3
February	9856
March	10198
April	12646
May	17949.7
June	21294
July	21074.68
August	14359
September	4056
October	6771
November	7016
December	6683

7. **Nussett No**
   Formula: Nu- 0.30 Re $(Vz)^{0.6}$

Month	Nussett No (Nu)
January	69.26
February	74.70
March	76.24
April	86.75
May	107.0
June	118.6
July	117.8
August	93.62
September	71.00
October	59.63
November	60.92
December	59.175

8. Heat Transfer Coefficient (W/m^2K)

Formula- $h= k_{air}/D_{out}*Nu$

Month	h
January	15.98
February	17.23
March	17.5
April	19.95
May	24.61
June	27.27
July	27.09
August	21.53
September	16.33
October	13.71
November	14.011
December	13.61

9. Linearized Radiation Coefficient

h_r- $4\sigma\varepsilon T_{air}^3$

Where σ – $5.6*10^{-8}$ (Stefan-Boltzmann constant)

ε -0.5

h_r- 3 W/m^2K (Emmittance of the surface)

10. Overall heat transfer over the year (W/m^2K)

Month	U
January	18.98
February	20.23
March	20.53
April	22.95
May	27.61
June	30.27
July	30.09
August	24.53
September	19.33
October	16.71
November	17.01
December	16.61

11. Thermal energy loss from receiver

Q_{loss}- $A_r U_L (T_{inner} – T_{air})$ Watt

Month	Qloss
January	1317.9
February	1404.56
March	1425.39
April	1593.14
May	1916.96
June	2101.64
July	2089.42
August	1703.11
September	1342.08
October	1160.17
November	1181.00
December	1153.23

12. Optical energy absorbed by receiver

Q_{opt}- $A_{aperture}*\rho*\tau*\alpha_r*I_a$

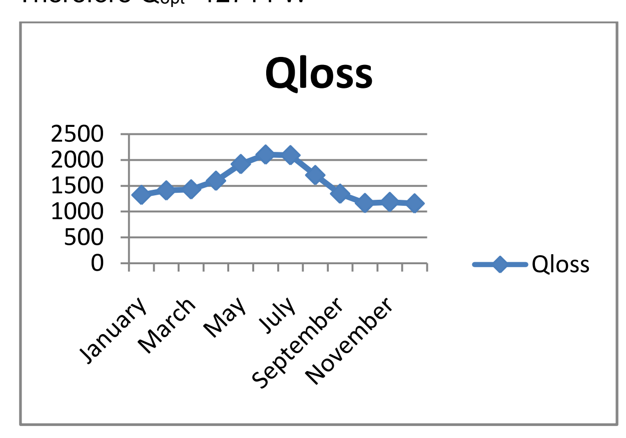
I_a- 1124.82 (average insolation incident on aperture)

α_r- 0.9

ρ- 1

A_a- 12.56m^2

Therefore Q_{opt}- 12714 W



13. Energy Produced by solar collector

Q_{out}- $Q_{opt} – Q_{loss}$ (W)

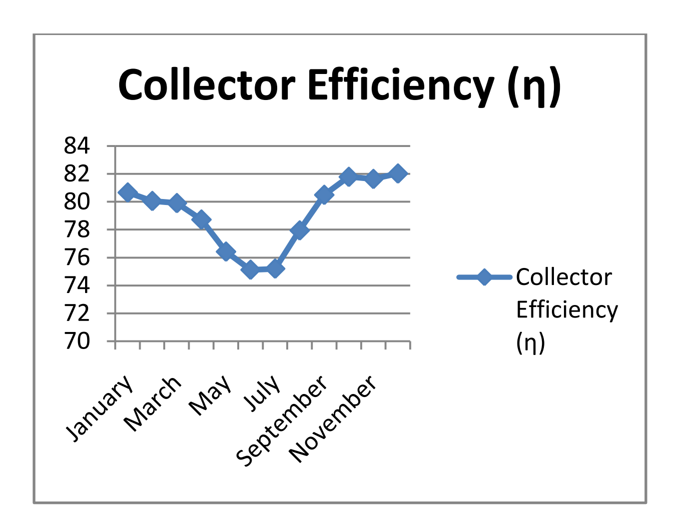
Month	Qout (W)
January	11396.1
February	11309.44
March	11288.61
April	11120.86
May	10797.04
June	10612.36
July	10624.58
August	11010.89
September	11371.92
October	11553.83
November	11533.00
December	11587.77

14. Collector Efficiency

$\eta_{collector}$- $Q_{out}/Aa\cdot Ia$

Month	Collector Efficiency (η)
January	80.66
February	80.05
March	79.90
April	78.72
May	76.42
June	75.12
July	75.20
August	77.94
September	80.49
October	81.78

November	81.63
December	82.02



Conclusion

This paper determines the influence of varied wind speeds on collector's efficiency of CSP. It is found that as the wind speed increases, collector's efficiency decreases. Therefore it is concluded that in order to achieve maximum collector's efficiency, we should be cautious regarding varying wind speed.

References

i. H. Clifford K and K. Gregory J, "Incorporating Uncertainty into Probabilistic Performance Models of Concentrating Solar Power Plants," Journal of Solar Energy Engineering, vol. 132, Aug. 2010.

ii. Wagner, M., and C Kutscher. 2010. The Impact of Hybrid Wet/Dry Cooling on Concentrating Solar Power Plant Performance. In Proceedings of the 4th International Conference on Energy Sustainability, ASME. Arizona, USA.

iii. Barea, J., Sara, M., and. Silva,M. 2010. Analysis of the influence of the monthly distribution of direct normal radiation in the production of parabolic trough plants using EOS. In Proceedings of SolarPACES 2010. Perpignan, France.

iv. Remund, J., Wald, L , Lefèvre, M , Ranchin, T and Page, J 2003. Worldwide Linke turbidity information. In Proceedings of the ISES Solar World Congress 2003. Göteborg, Sweden

v. Hoyer-Klick, C., Hustig,F., Schwandt, M.and Meyer,R., 2009. Characteristic Meteorological Years from Ground and Satellite Data. In Proceedings of SolarPACES 2009. Berlin, Germany.

vi. Bella, E., Ramirez, L., Drews, A., Beyer, H.G., Zarzalejo, L.F.., J. Polo, and Martin, "Analysis of different comparison parameters applied to solar\line radiation data from satellite and German radiometric stations," Solar Energy, vol. 83 (2009), Jul. 2008, pp. 118.